Agricultural Biomass Resource Assessment in Cambodia, Lao and Viet Nam

Asian Development Bank

Greater Mekong Subregion

Capacity Building for Efficient Utilization of Biomass for Bioenergy & Food Security in the GMS

TA-7833 REG

TECHNICAL REPORT:

AGRICULTURAL BIOMASS RESOURCE ASSESSMENT IN CAMBODIA, LAO & VIET NAM

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Landell Mills
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ABBREVIATIONS AND ACRONYMS

AD	Anaerobic Digestion
ADB	Asian Development Bank
BTU	British Thermal Unit
cm	centimeter
CO^2	Carbon dioxide
EA	Executing Agency
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouse Gas
GJ	Gigajoule
ha	Hectare
IA	Implementing Agency
ICS	Improved Cook Stoves
ILUC	Indirect Land Use Change
LCA	Life-cycle Assessment
LHV	Lower heating value (net calorific value) to determine potential energy
LML	Landell Mills Limited
MCA	Multi-Criteria Analysis
PDR	People's Democratic Republic
PRC	People's Republic of China
RED	Renewable Energy Directive
RHC	Rice Husk Char
RPR	Residue Product Ratio
t	Tonne
TA	Technical Assistance
tC	Tons of carbon
TNA	Technology Needs Assessment
ToR	Terms of Reference
TRLs	Technology Readiness Levels
UK	United Kingdom
UNDP	United Nations Development Programme
UNFCCC	UN Framework Convention on Climate Change

EXECUTIVE SUMMARY

The report provides a high-level assessment of the potential biomass stocks from agricultural residues and livestock waste in Cambodia, Lao PDR and Viet Nam expressed as: quantities of biomass produced annually, their intensity per hectare of farmed area and their potential energy value. This provides an indication of total potential biomass feedstocks for biogas, pyrolysis and gasification or non-energy uses such as a soil fertiliser. The Table below summarises the findings in terms of tonnes (dry basis) and theoretical energy content of biomass as a % of primary energy use.

Table 1: Biomass agri-residue resources in Cambodia, Lao PDR and Viet Nam

Biomass agri-residue resource (in million tonnes) (2007-2011 average) (FAO)	**Cambodia**	**Lao PDR**	**Viet Nam**
Crops			
Rice husk	1.85	0.60	8.82
Rice bran	0.85	0.33	2.94
Rice straw	7.99	2.54	33.31
Maize stalks	1.29	1.84	9.02
Maize cobs	0.19	0.28	1.23
Maize husks	0.14	0.20	0.90
Cassava stalk	0.22	0.02	0.55
Sugar cane tops	0.11	0.19	4.97
Sugar cane bagasse	0.10	0.19	4.80
Sub-total	**12.74**	**6.19**	**66.54**
% of primary energy use (theoretical potential)	**26.97**	**238.35**	**48.42**
Animals			
Cattle manure	13.84	6.31	18.25
Pig manure	4.32	2.82	20.30
Chicken manure	1.40	0.47	5.85
Buffalo manure	4.40	7.46	12.93
Sub-total	**23.96**	**17.06**	**57.33**
% of primary energy use (theoretical potential)	**56.05**	**585.61**	**47.81**
Overall total	**36.70**	**23.25**	**114.35**
% of primary energy use (theoretical potential)	**83.02**	**823.96**	**96.23**

The methodology for crops involves identifying the Resource Product Ratio (RPR) for each agri-residue - as far as possible specific to each country. FAO data provides total crop yield and the energetic value is obtained from literature values. For animals, country-specific estimates of manure generation per head per year are used wherever possible, alongside energy values from the literature.

Biomass listed in the Table is often already used, to differing extents, as animal feed (husks, straw, cobs, stalks), input to human food supply chain (e.g. rice bran), animal bedding (straws and husks), fuel (straw, cobs, husk, bagasse, manure) or fertiliser (manure). Large amounts of biomass remain under-utilised however. The realistic energy potential is usually much lower than the theoretical potential due to: a) competing uses of the biomass and; b) the energy losses in converting biomass into deliverable energy for power or heat (the efficiency of conversion varying from 5 to 90% depending upon the conversion route and technology). Because of this wide variation in competition, price and conversion efficiency, evaluation of realistic potential requires detailed spatially-specific studies.

Biomass has a low energy density per hectare (compared to fossil fuels) and its utilisation depends critically upon the economics of removal and aggregation. Where this happens for other reasons (e.g. rice husk removed during paddy rice milling), the economic case is more compelling than

where the cost of collection has to be covered by the energy producing enterprise (as with much straw collection). Equally important is the availability of surplus rural labor (something that is rapidly declining in both Viet Nam and Cambodia) and the marginal cost of other (non-biomass) power sources including diesel and grid electricity. For example, the cost of other energy sources in Cambodia is relatively high whilst in Viet Nam it is extremely low making investment into biomass energy generation less likely.

1. INTRODUCTION

This report seeks to give a high-level assessment of the potential biomass stocks from agricultural crop residues and livestock waste in Cambodia, Lao People's Democratic Republic (PDR), and Viet Nam.

National figures have been gathered and analyzed to give an indication of what quantities of biomass are produced annually, their intensity per hectare of farmed area and their potential energy value. A brief description of the residue, as well as its current and competing uses is also provided.

It is envisaged that this data will be supplemented by sub-national data (e.g. province, district and/or commune) as it is gathered during the course of TA7833-REG implementation; some examples are shown in **Appendix 2**.

These figures will be vital in assessing existing uses of the biomass stocks and what fraction of the supply would potentially be available for applications in bioenergy systems such as biogas, pyrolysis and gasification.

2. AGRICULTURAL RESIDUES: CROPS

The residues discussed in this chapter were assessed using data from the Food and Agriculture Organization of the United Nations (FAO) on total crop production for 2007-2011 and Residue Product Ratios (RPRs), which indicate the amount of residue generated per unit of production.

There is a wide variety of species, varieties and cutlivars in addition to different cultivation, harvesting and processing methods employed across the world for these crops, which contributes to a wide range of RPRs. Regional assessments of local practice will help narrow these figures to provide a more exact estimate of available biomass.

Assumptions used for the calculations in this report - such as RPRs and Lower Heating Value[1] (LHV) - are given in **Appendix 1**.

2.1. RICE

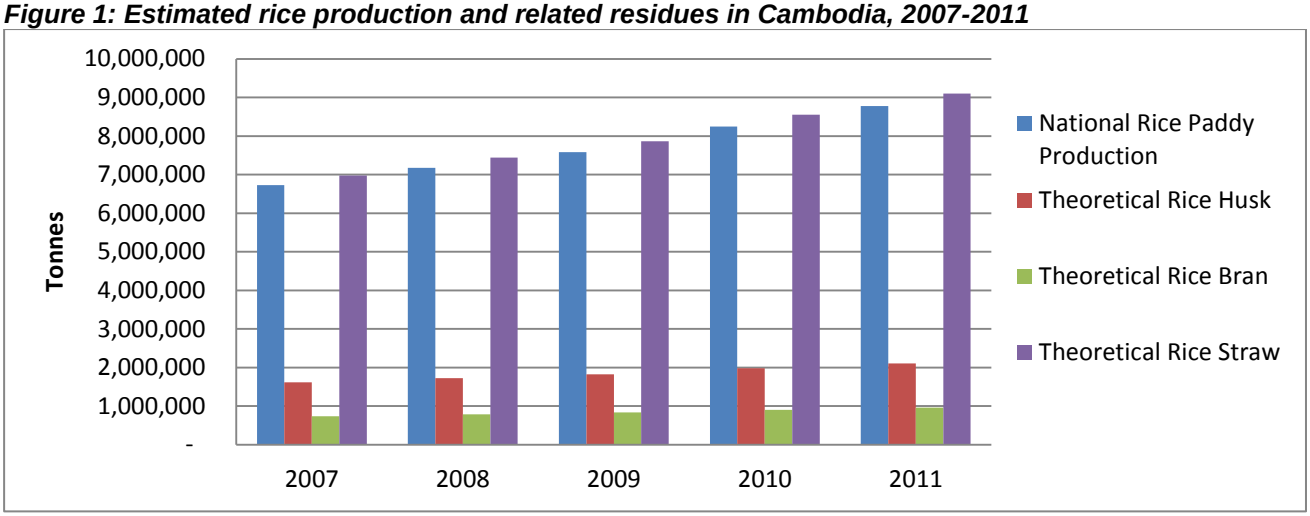
Typical paddy rice harvested across Southeast Asia is separated into the grain, husk, straw and bran (also called mash). The straw is collected from the field after the harvest, while the grain, husk and bran are separated during processing - generally at a rice mill. Regional intensity figures for each country for rice production, harvest area and yield are included in **Appendix 2**.

Historically, rice straw has been a common cooking fuel in rural areas. In Viet Nam, recent improvements in fuel availability have decreased the amount used by households, but increased the amount burned in the fields after threshing. Rice straw is also commonly used for cattle bedding but this demand has been reducing with a trend towards reduction in cattle livestock numbers per household with greater mechanization.

Rice husks are most commonly used as fuel by rice mills. In Cambodia, rice mills use roughly 42% of rice husk stock for fuel, while selling much of the remainder to factories (e.g. brick kilns), alcohol producers, farmers and others; of which 90% is then burned as a fuel.[2]

2.1.1. Cambodia

Figure 1: Estimated rice production and related residues in Cambodia, 2007-2011



Source: FAOStat, 2013

[1] *Also referred to as net calorific value*

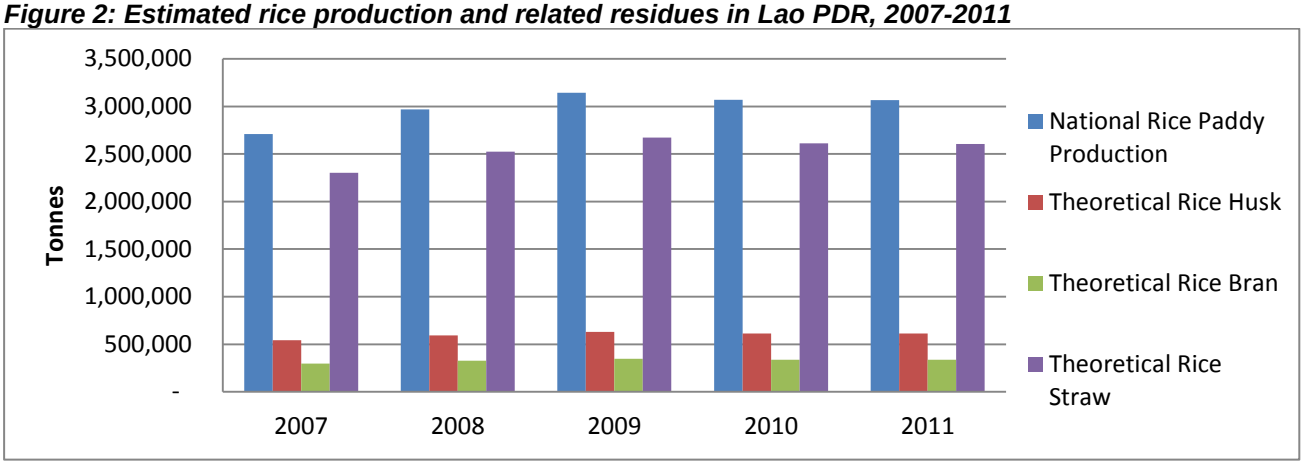
[2] *Bryan et al. (2012). Non-Renewable Biomass Assessment in Laos. Nexus-Carbon for Development. February 2012.*

Table 2: Average estimated rice production & residue characteristics in Cambodia, 2007-11

Total paddy rice production (t)	Quantity of husk (t)	Quantity of bran (t)	Quantity of straw (t)	Quantity of straw collected (t)	Potential energy[3] - husk (10^6 GJ)
7,702,532	1,848,608	847,279	9,397,089	7,987,526	23.75
Area of crop (ha)	**Paddy yield per ha (t)**	**Husk yield per ha (t)**	**Straw yield per ha (t)**	**Bran yield per ha (t)**	**Potential energy - straw (10^6 GJ)**
2,711,294	2.83	0.68	2.94	3.22	111.83

2.1.2. Lao PDR

Figure 2: Estimated rice production and related residues in Lao PDR, 2007-2011



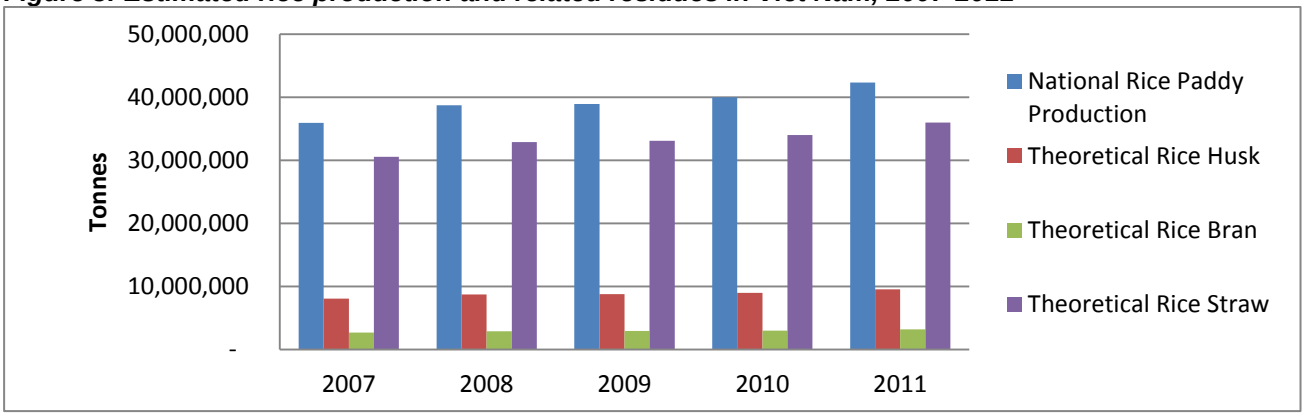
Source: FAOStat, 2013

Table 3: Average estimated rice production & residue characteristics in Lao PDR, 2007-11

Total paddy rice production (t)	Quantity of husk (t)	Quantity of bran (t)	Quantity of straw (t)	Quantity of straw collected (t)	Potential energy - husk (10^6 GJ)
2,992,232	598,446	329,146	2,992,232	2,543,397	7.69
Area of crop (ha)	**Paddy yield per ha (t)**	**Husk yield per ha (t)**	**Straw yield per ha (t)**	**Bran yield per ha (t)**	**Potential energy - straw (10^6 GJ)**
801,011	3.74	0.75	3.18	2.43	35.61

2.1.3. Viet Nam

Figure 3: Estimated rice production and related residues in Viet Nam, 2007-2011



Source: FAOStat, 2013

[3] *Potential energy measured as lower heating value (LHV) or net calorific value (NCV)*

Table 4: Average estimated rice production & residue characteristics in Cambodia, 2007-11

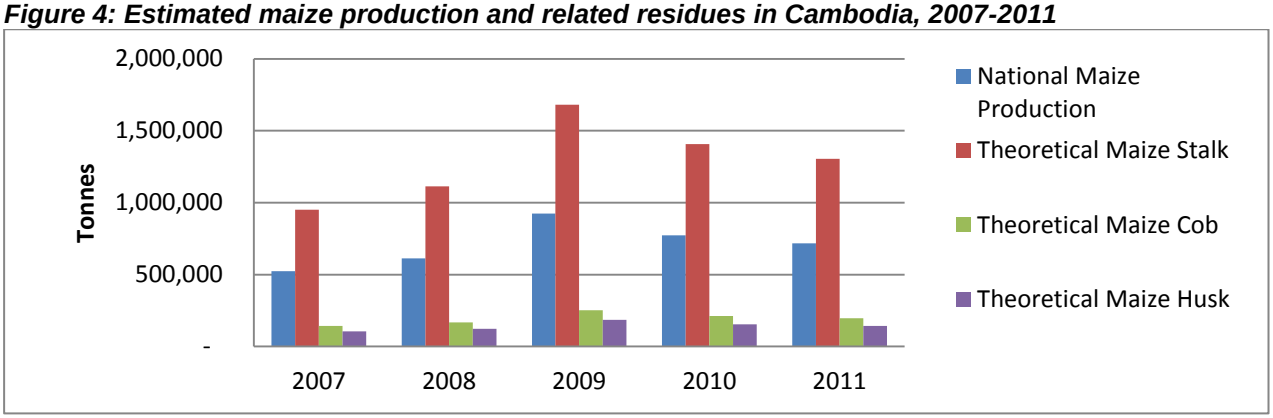
Total paddy rice production (t)	Quantity of husk (t)	Quantity of bran (t)	Quantity of straw (t)	Quantity of straw collected (t)	Potential energy - husk (10^6 GJ)
39,191,980	8,818,196	2,939,399	39,191,980	33,313,183	113.31
Area of crop (ha)	**Paddy yield per ha (t)**	**Husk yield per ha (t)**	**Straw yield per ha (t)**	**Bran yield per ha (t)**	**Potential energy - straw (10^6 GJ)**
7,437,220	5.27	1.18	4.48	2.53	466.38

2.2. MAIZE

Corn stovers consist of the leaves and stalks of the maize plant and make up a significant part of available biomass where maize is grown intensively. During processing, the maize husks and cob are also separated from the product. Maize residue quantities can be significant and their use varies by region. Along with burning for cooking and fuel, maize residues are also used as animal feed and for composting.

2.2.1. Cambodia

Figure 4: Estimated maize production and related residues in Cambodia, 2007-2011



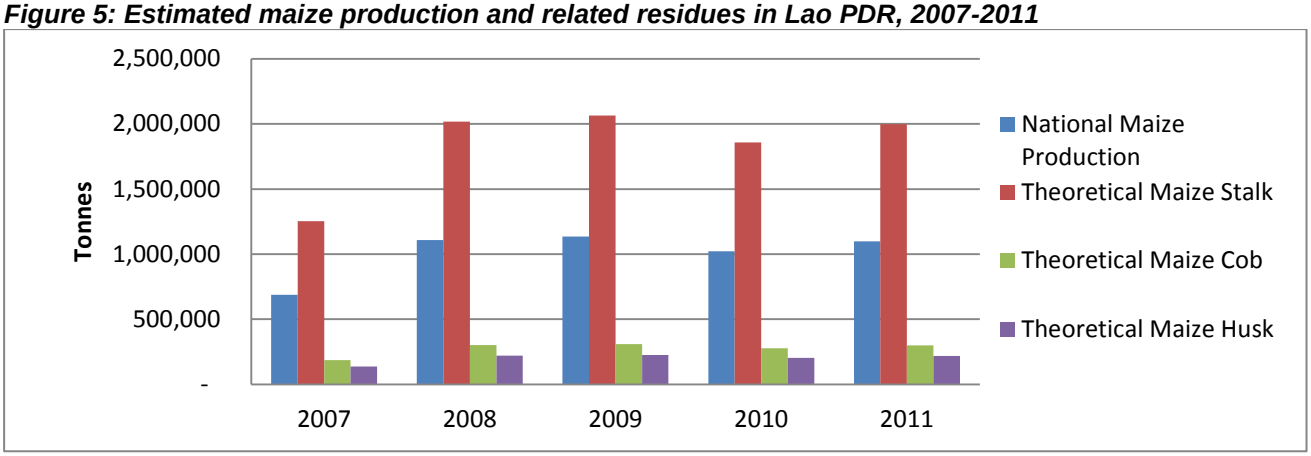
Source: FAOStat, 2013

Table 5: Average estimated maize production & residue characteristics in Cambodia, 2007-11

Total maize Production (t)	Quantity of stalks (t)	Quantity of cob (t)	Quantity of husks (t)
709,832	1,419,664	193,784	141,966
Area of crop (ha)	**Potential energy - stalk (10^6 GJ)**	**Potential energy - cob (10^6 GJ)**	**Potential energy - husk (10^6 GJ)**
235,343	21.95	22.60	2.52
Maize yield per ha (t)	**Stalk yield per ha (t)**	**Cob yield per ha (t)**	**Husks yield per ha (t)**
3.24	5.89	0.88	0.65

2.2.2. Lao PDR

Figure 5: Estimated maize production and related residues in Lao PDR, 2007-2011



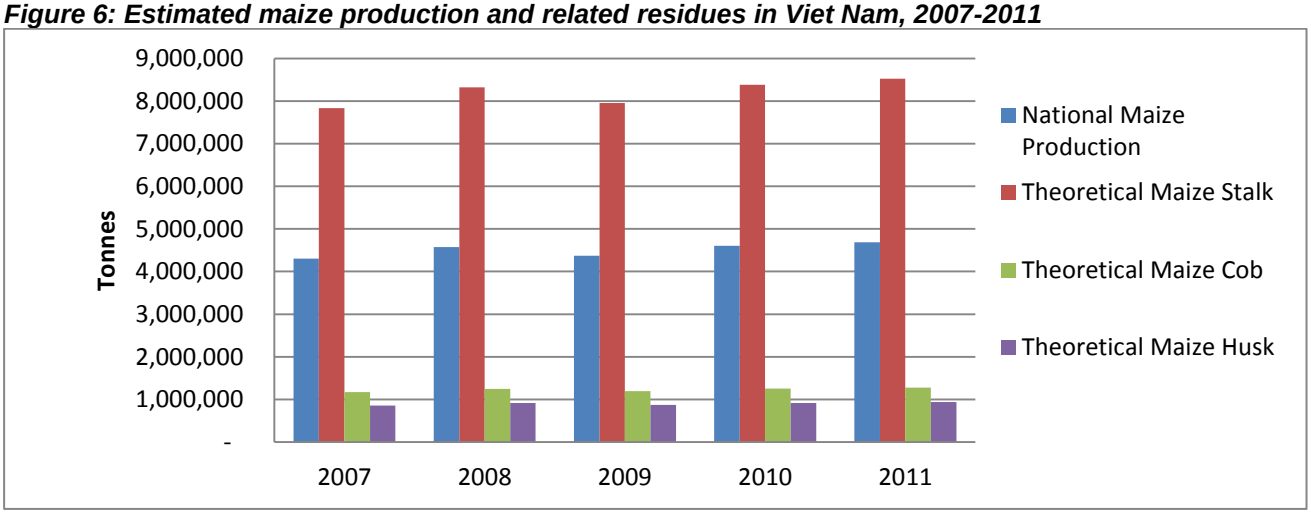
Source: FAOStat, 2013

Table 6: Average estimated maize production & residue characteristics in Lao PDR, 2007-11

Total maize production (t)	Quantity of stalks (t)	Quantity of cob (t)	Quantity of husks (t)
1,009,846	2,019,692	275,688	201,969
Area of crop (ha)	**Potential energy - stalk (10^6 GJ)**	**Potential energy - cob (10^6 GJ)**	**Potential energy - husk (10^6 GJ)**
203,876	31.23	32.15	3.58
Maize yield per ha (t)	**Stalk yield per ha (t)**	**Cob yield per ha (t)**	**Husks yield per ha (t)**
4.93	8.97	1.35	0.99

2.2.3. Viet Nam

Figure 6: Estimated maize production and related residues in Viet Nam, 2007-2011



Source: FAOStat, 2013

Table 7: Average estimated maize production & residue characteristics in Vietnam, 2007-11

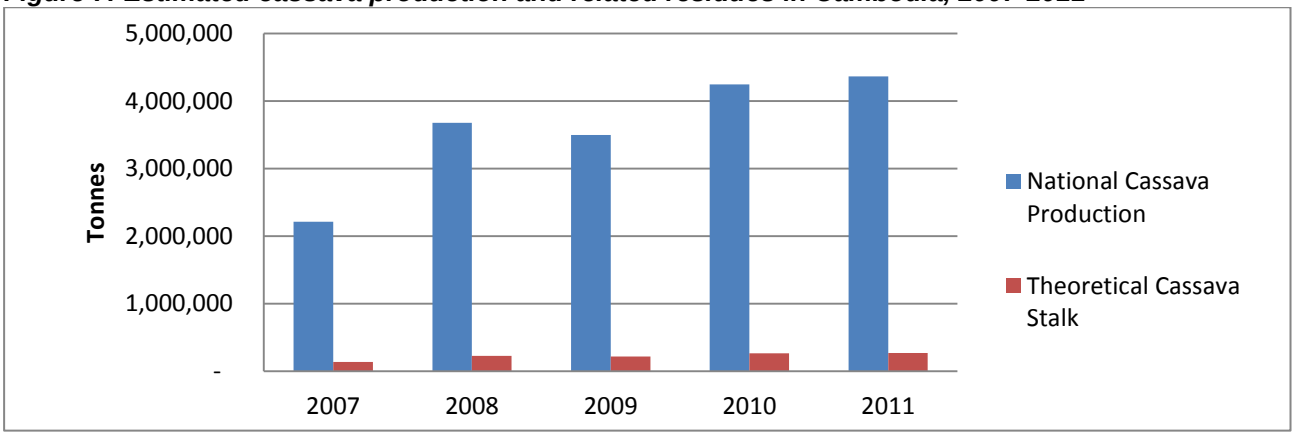
Total production (t)	Quantity of stalk (t)	Quantity of cob (t)	Quantity of husk (t)
4,507,820	9,015,640	1,230,635	901,564
Area of crop (ha)	**Potential energy - stalk (10^6 GJ)**	**Potential energy - cob (10^6 GJ)**	**Potential energy - husk (10^6 GJ)**
1,166,578	139.39	143.49	15.98
Yield per ha (t)	**Stalk yield per ha (t)**	**Cob yield per ha (t)**	**Husk yield per ha (t)**
3.91	7.11	1.07	0.78

2.3. CASSAVA

At harvest time, the cassava plant is first topped before being fully uprooted. The small part removed is considered the stalk, a portion of which is recycled through replanting. The remainder is sometimes left in the field or used for burning. The amount used for replanting varies from region to region. In many rural areas, cassava stalks are used for cooking, animal feed and for compost.

2.3.1. Cambodia

Figure 7: Estimated cassava production and related residues in Cambodia, 2007-2011



Source: FAOStat, 2013

Table 8: Average estimated cassava production & residue characteristics in Cambodia, 2007-11

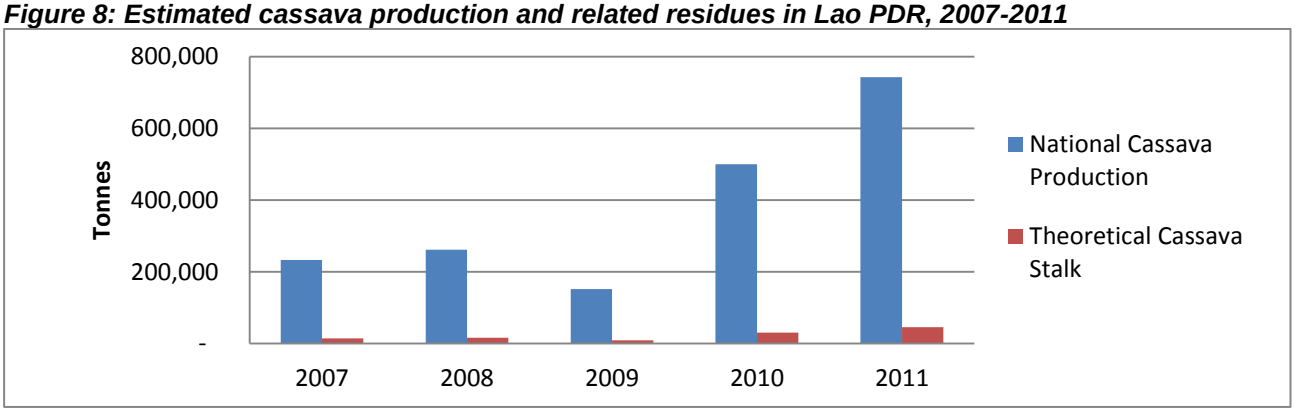
Total Cassava Production (t)	Quantity of Stalk (t)	Area of Crop (ha)	Cassava Yield per ha (t)	Stalk Yield per ha (t)	Potential Energy - Stalk (10^6 GJ)
3,600,824	223,251	171,140	21.01	1.30	3.79

2.3.2. Lao PDR

Table 9: Average estimated cassava production & residue characteristics in Lao PDR, 2007-11

Total Cassava Production (t)	Quantity of Stalk (t)	Area of Crop (ha)	Cassava Yield per ha (t)	Stalk Yield per ha (t)	Potential Energy - Stalk (10^6 GJ)
378,252	23,452	17,492	20.46	1.27	0.40

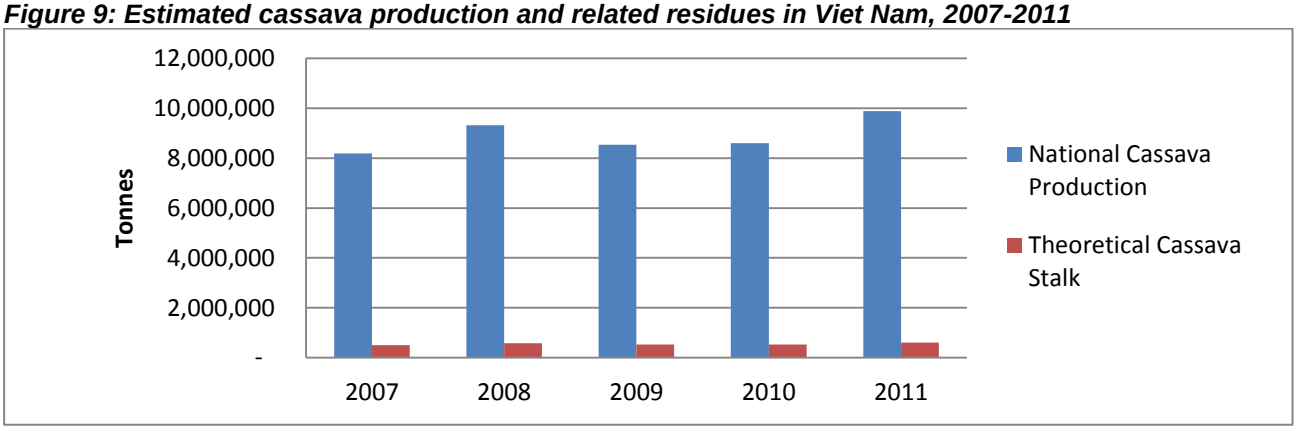
Figure 8: Estimated cassava production and related residues in Lao PDR, 2007-2011



Source: FAOStat, 2013

2.3.3. Viet Nam

Figure 9: Estimated cassava production and related residues in Viet Nam, 2007-2011



Source: FAOStat, 2013

Table 10: Average estimated cassava production & residue characteristics in Vietnam, 2007-11

Total Cassava Production (t)	Quantity of Stalk (t)	Area of Crop (ha)	Cassava Yield per ha (t)	Stalk Yield per ha (t)	Potential Energy - Stalk (10^6 GJ)
8,900,860	551,853	523,080	17.01	1.05	9.38

2.4. SUGAR CANE

Sugar cane is an intensive crop that creates a significant tonnage of product and residue per area harvested. In the fields, the sugar cane is first separated from the sugar cane tops (trash) in the fields, while bagasse is a result of processing. Roughly 80% of bagasse produced at sugar mills is burned to fire boilers to produce electricity and heat for the mill and refining processes. The remaining tops can also be burned for fuel, which is most common by farmers living in proximity to the sugar cane fields.

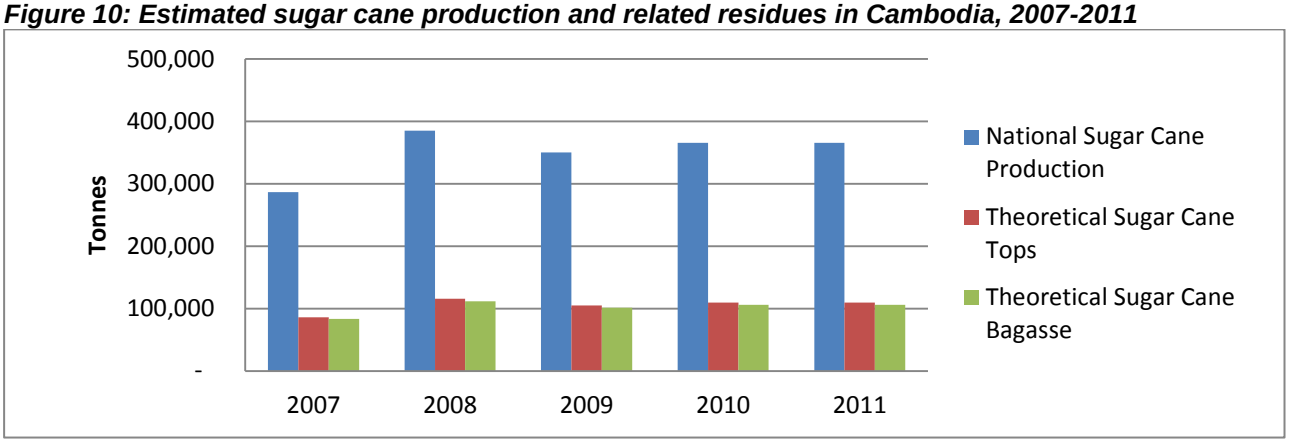
2.4.1. Cambodia

Table 11: Average estimated sugarcane production & residue characteristics in Cam, 2007-11

Total Sugar Cane Production (t)	Quantity of Tops (t)	Quantity of Bagasse (t)	Potential Energy - Tops (10^6 GJ)	Area of Crop (ha)
350,663	105,199	101,692	0.72	14,286
Sugar Cane Yield per ha (t)	**Tops Yield per ha (t)**	**Bagasse Yield per ha (t)**	**Potential Energy - Bagasse (10^6 GJ)**	

25.02	7.51	7.26	0.65	

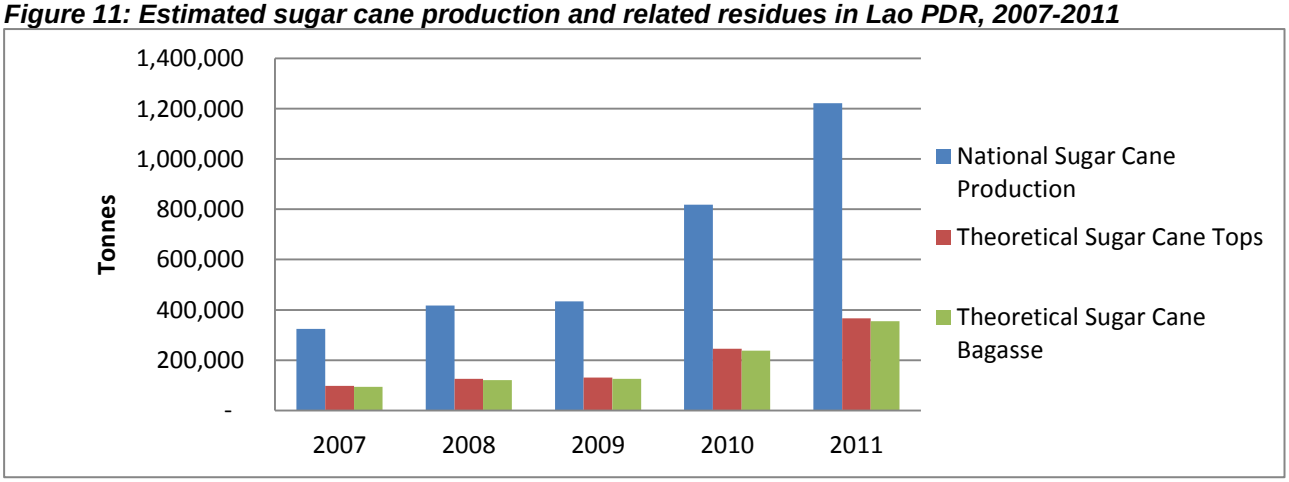
Figure 10: Estimated sugar cane production and related residues in Cambodia, 2007-2011



Source: FAOStat, 2013

2.4.2. Lao PDR

Figure 11: Estimated sugar cane production and related residues in Lao PDR, 2007-2011



Source: FAOStat, 2013

Table 12: Average estimated sugarcane production & residue characteristics in Lao, 2007-11

Total Sugar Cane Production (t)	Quantity of Tops (t)	Quantity of Bagasse (t)	Potential Energy - Tops (10^6 GJ)	Area of Crop (ha)
642,956	192,887	186,457	1.32	14,856
Sugar Cane Yield per ha (t)	**Tops Yield per ha (t)**	**Bagasse Yield per ha (t)**	**Potential Energy - Bagasse (10^6 GJ)**	
41.48	12.44	12.03	1.20	

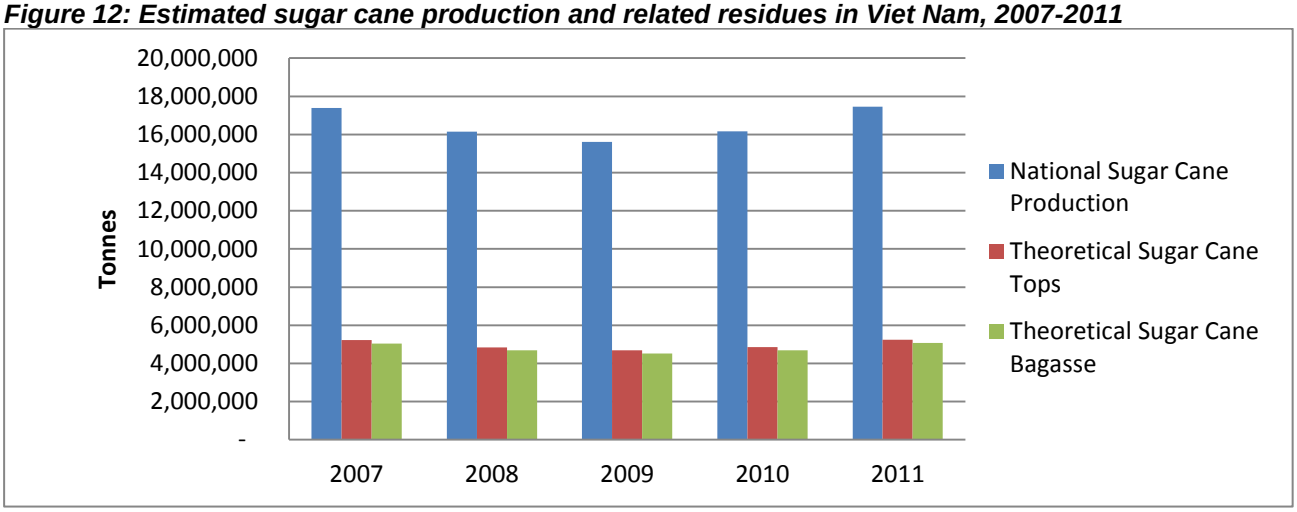
2.4.3. Viet Nam

Table 13: Average estimated sugarcane production & residue characteristics in Viet Nam, 2007-11

Total sugar Cane Production (t)	Quantity of Tops (t)	Quantity of Bagasse (t)	Potential Energy - Tops (10^6 GJ)	Area of Crop (ha)
16,555,480	4,966,644	4,801,089	33.87	276,020
Sugar Cane Yield per ha (t)	**Tops Yield per ha (t)**	**Bagasse Yield per ha (t)**	**Potential Energy - Bagasse (10^6 GJ)**	

59.97	17.99	17.39	30.87	

Figure 12: Estimated sugar cane production and related residues in Viet Nam, 2007-2011



Source: FAOStat, 2013

3. AGRICULTURAL RESIDUES: LIVESTOCK

This chapter assesses the potential from pigs, cattle, chickens and buffalo manure.

Given the large livestock populations throughout Southeast Asia, improved waste management can potentially provide a significant source of energy, while reducing greenhouse gas emissions, environmental pollution and related health risks.

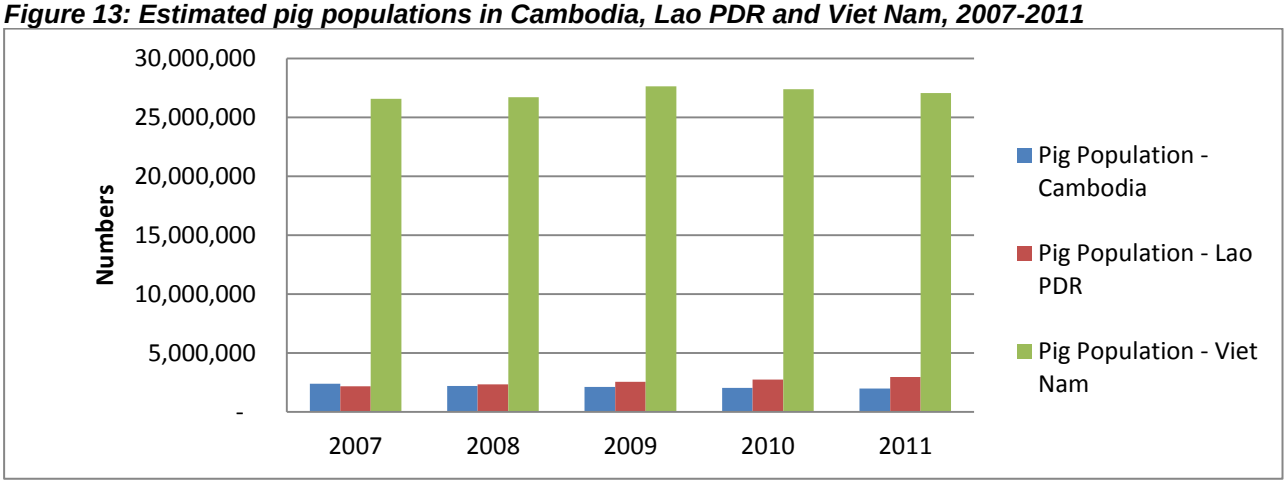
There is little national data on total manure quantities. Using total livestock populations in the three countries of study and average manure per head figures collected from country sources, an estimate has been produced of total manure availability.

Bioslurry, which is the output of small-scale anaerobic digestion (biogas) reactors that have proliferated in recent years across Southeast Asia, was also estimated. Assumptions used for these calculations are given in **Appendix 1**.

Regarding current residue use for manure, it is difficult to speak generally about manure management across Southeast Asia as different regions are at various stages of development. Traditionally, manure is primarily used for composting, but popular biogas reactors are increasingly used by small households, and in some cases full-scale anaerobic digestion plants are installed at large livestock farms.

3.1. PIGS

Figure 13: Estimated pig populations in Cambodia, Lao PDR and Viet Nam, 2007-2011



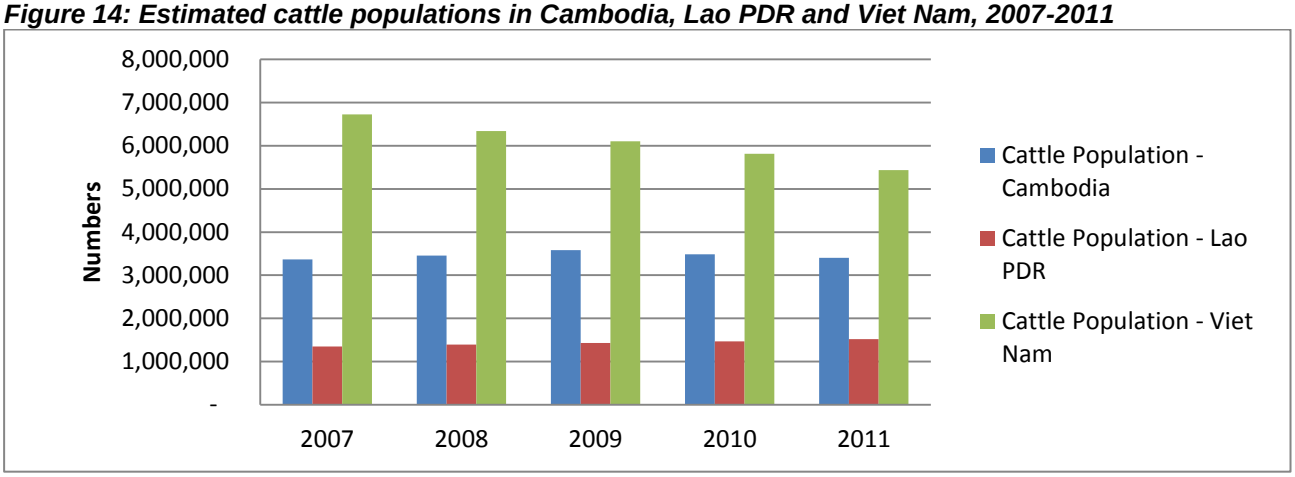
Source: FAOStat, 2013

Table 14: Ave. est. pig populations & manure characteristics in Cam, Lao & Vietnam, 2007-11

Country	Population	Total Manure (t)	Total Bioslurry (m^3)	Potential Energy - Manure (10^6 GJ)
Cambodia	2,157,752	4,315,504	4,602,522	73.1
Lao PDR	2,563,200	2,819,520	3,007,042	47.7
Viet Nam	27,063,860	20,297,895	21,647,877	343.6

3.2. CATTLE

Figure 14: Estimated cattle populations in Cambodia, Lao PDR and Viet Nam, 2007-2011



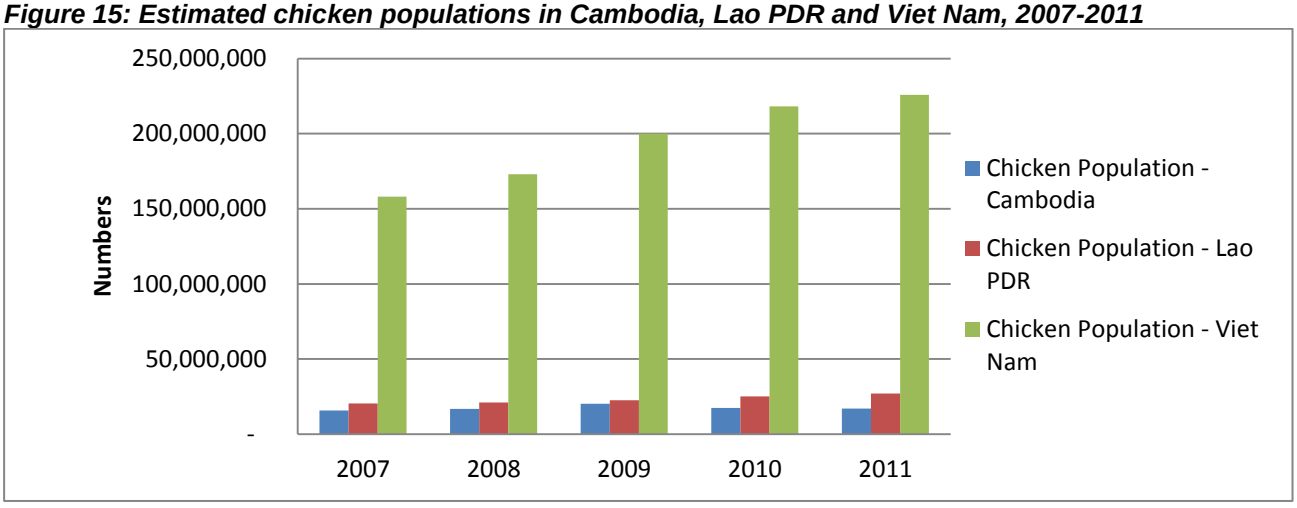
Source: FAOStat, 2013

Table 15: Ave. est. cattle populations & manure characteristics in Cam, Lao & Vietnam, 2007-11

Country	Population	Total Manure (t)	Total Bioslurry (m^3)	Potential Energy - Manure (10^6 GJ)
Cambodia	3,459,538	13,838,152	14,758,506	224.0
Lao PDR	1,434,800	6,313,120	6,732,996	102.2
Viet Nam	6,082,120	18,246,360	19,459,898	295.4

3.3. CHICKENS

Figure 15: Estimated chicken populations in Cambodia, Lao PDR and Viet Nam, 2007-2011



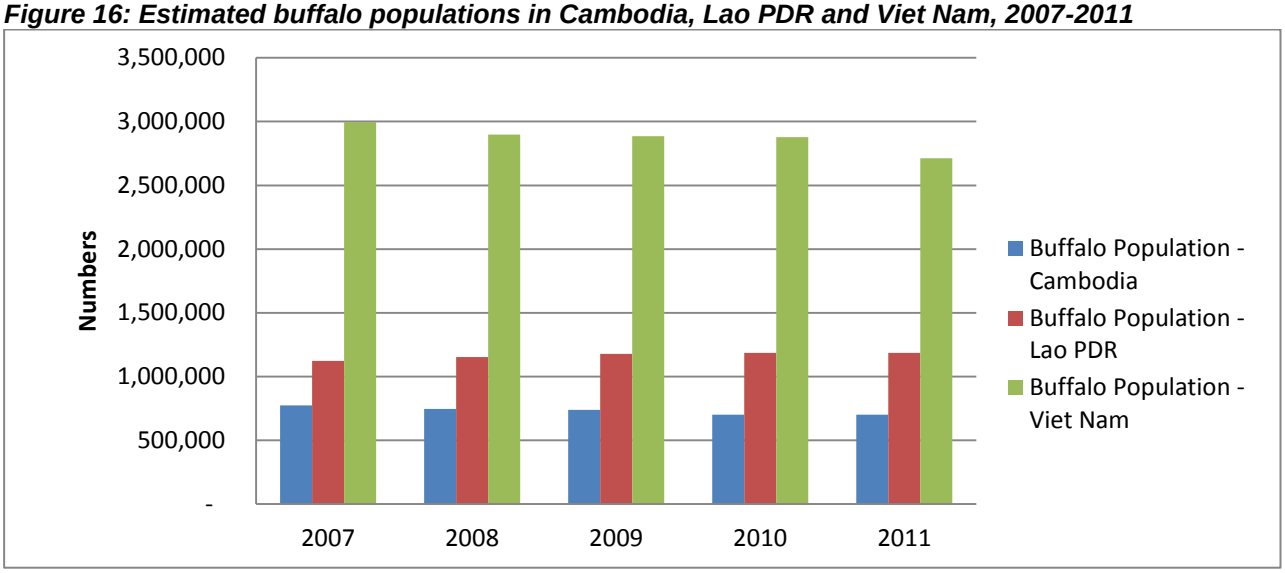
Source: FAOStat, 2013

Table 16: Ave. est. chicken populations & manure characteristics in Cam, Lao & Vietnam, 2007-11

Country	Population	Total Manure (t)	Total Bioslurry (m^3)	Potential Energy - Manure (10^6 GJ)
Cambodia	17,478,800	1,398,304	1,491,303	22.1
Lao PDR	23,260,200	465,204	496,144	7.3
Viet Nam	195,066,200	5,851,986	6,241,193	92.3

3.4. BUFFALO

Figure 16: Estimated buffalo populations in Cambodia, Lao PDR and Viet Nam, 2007-2011



Source: FAOStat, 2013

Table 17: Ave. est. buffalo populations & manure characteristics in Cam, Lao & Vietnam, 2007-11

Country	Population	Total Manure (t)	Total Bioslurry (m^3)	Potential Energy - Manure (10^6 GJ)
Cambodia	732,556	4,395,337	4,687,664	71.2
Lao PDR	1,165,400	7,458,560	7,954,617	120.8
Viet Nam	2,873,940	12,932,730	13,792,866	209.4

4. COUNTRY SUMMARY

This assessment has sought to show an overview of the amounts of biomass available from crop and livestock waste in the three target countries of Cambodia, Lao PDR and Viet Nam. The following figures compare the different biomass quantities available in each country, as well as their corresponding energy potentials. Calculations were also made to assess what percent of current primary energy use in the three countries could be accounted for with the potential energy of the residues considered in this study.

Details on assumptions and calculations may be found in **Appendix 1**. It is important to note that there is a very large difference between *potential* energy and *realizable* (or delivered) energy at the point of use. The values shown in the figures below are the total potential if *all* agri-residues and animal wastes were used for bioenergy production - which is practically impossible due to competition for a portion of that biomass for other applications.

Furthermore, the value reflects the total energy content of the biomass. The deliverable energy that may be extracted from the biomass resource is only ever a fraction of this total due to losses during conversion processes. The efficiency will depend upon the conversion route and may vary from 90% (heat production) to 5% (some traditional cookstoves). Because of this very wide range we only present the total potential energy content.

4.1. CAMBODIA

Figure 17: Estimated annual tonnage of agricultural and livestock residue in Cambodia

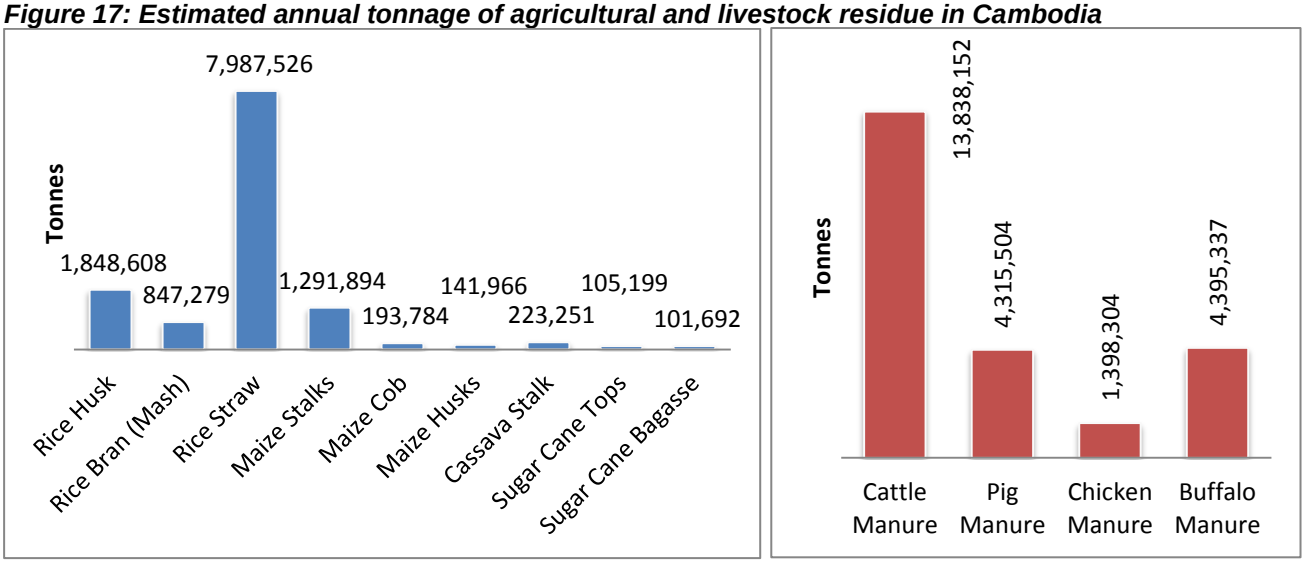


Figure 18: Estimated annual potential energies of agricultural and livestock residue in Cambodia

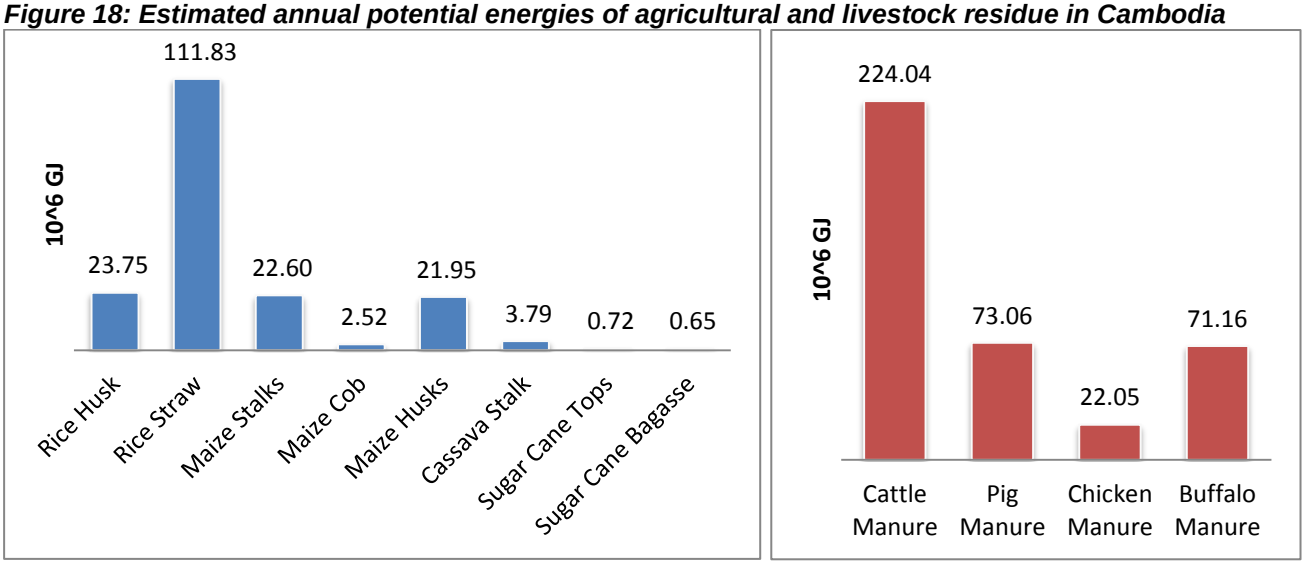


Figure 19: Potential energy of crop residues as a percentage of primary energy use, Cambodia

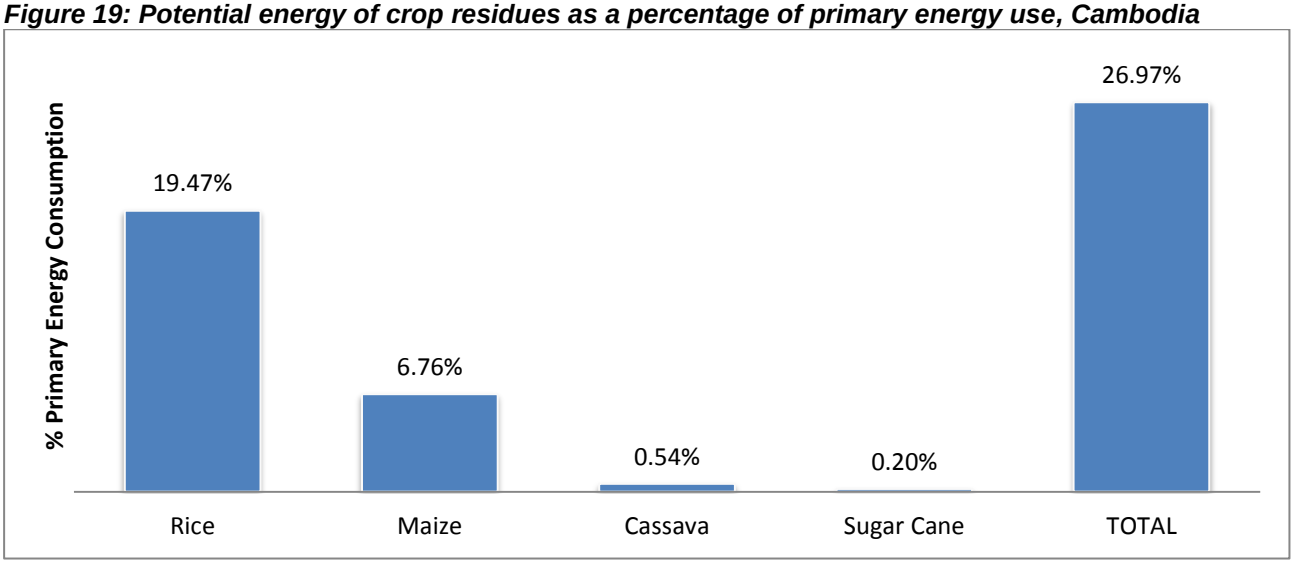
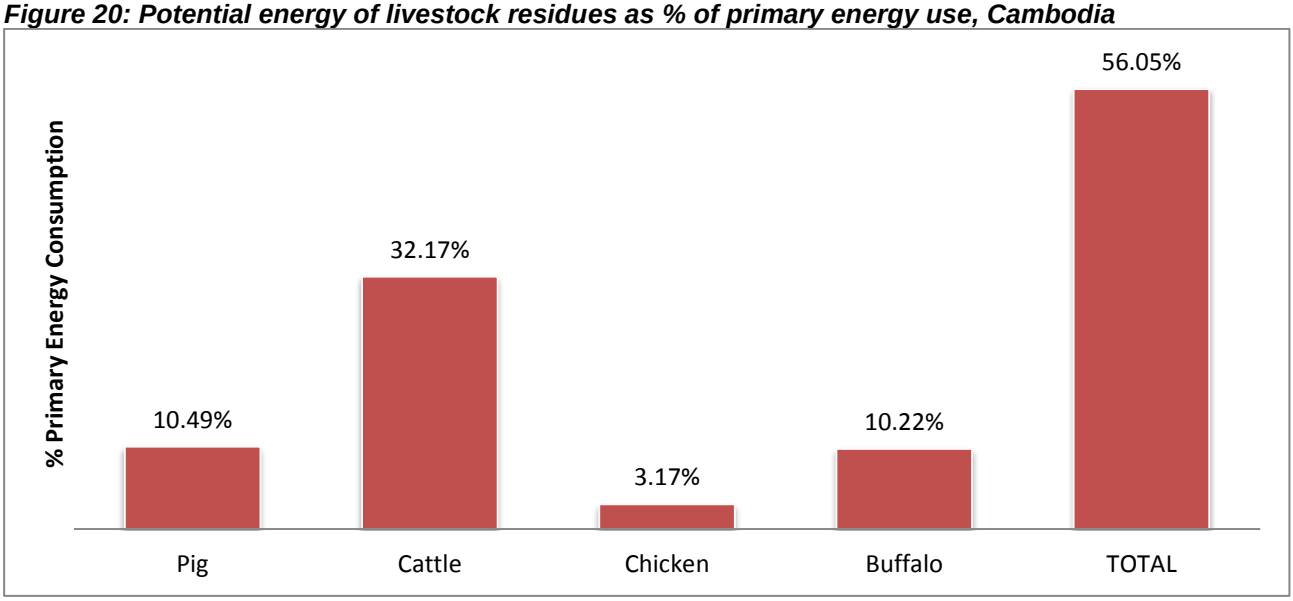


Figure 20: Potential energy of livestock residues as % of primary energy use, Cambodia



4.2. LAO PDR

Figure 21: Estimated annual potential energies of agricultural and livestock residue in Lao PDR

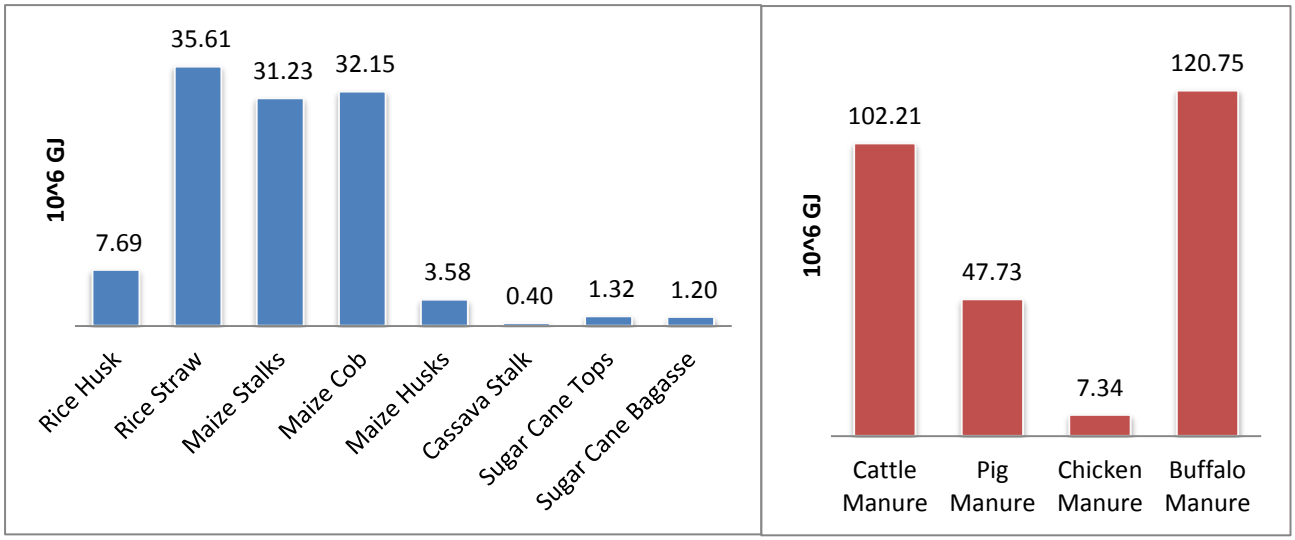


Figure 22: Estimated annual tonnage of agricultural and livestock residue in Lao PDR

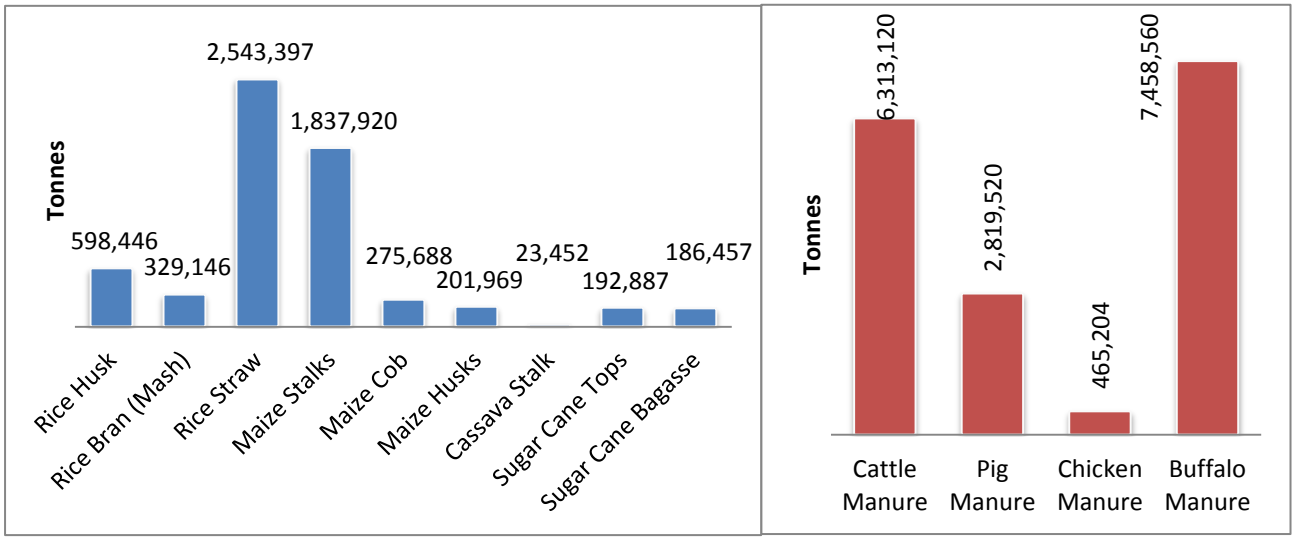


Figure 23: Potential energy of crop residues as a percentage of primary energy use in Lao PDR

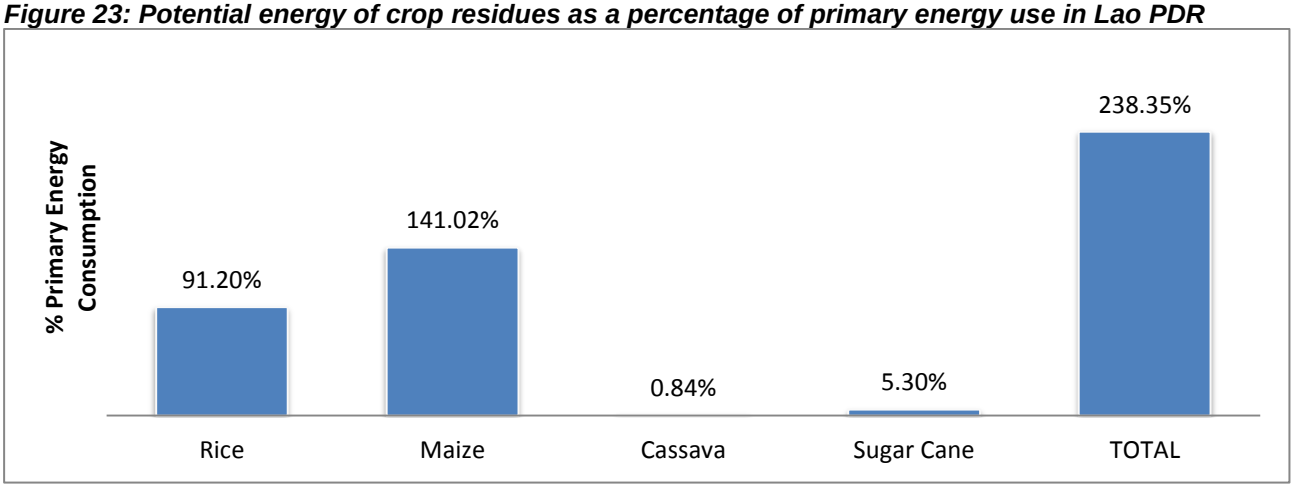
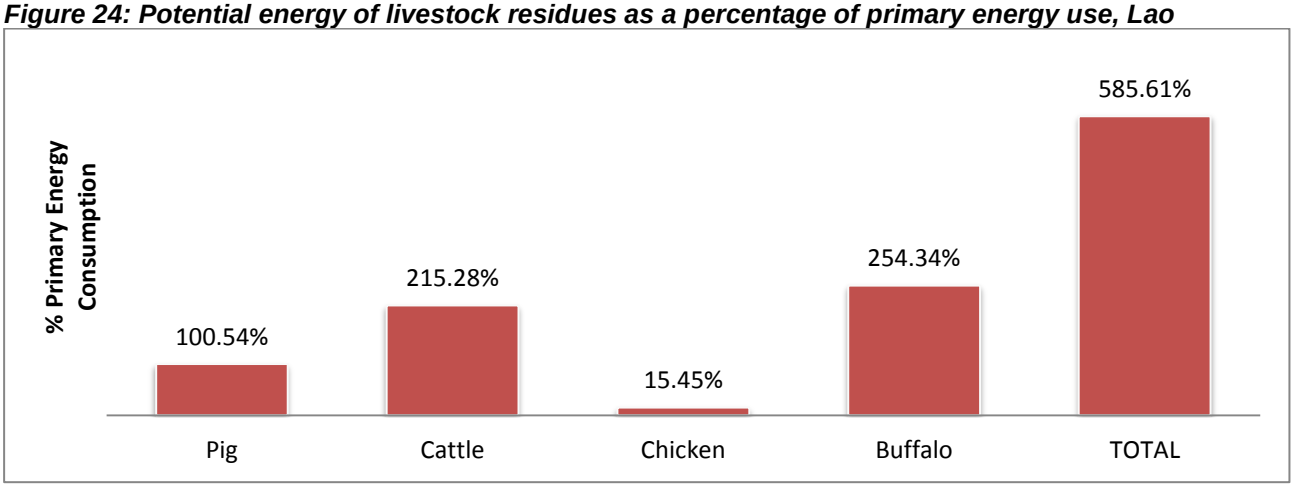


Figure 24: Potential energy of livestock residues as a percentage of primary energy use, Lao



4.3. VIET NAM

Figure 25: Estimated annual potential energies of agricultural and livestock residue in Viet Nam

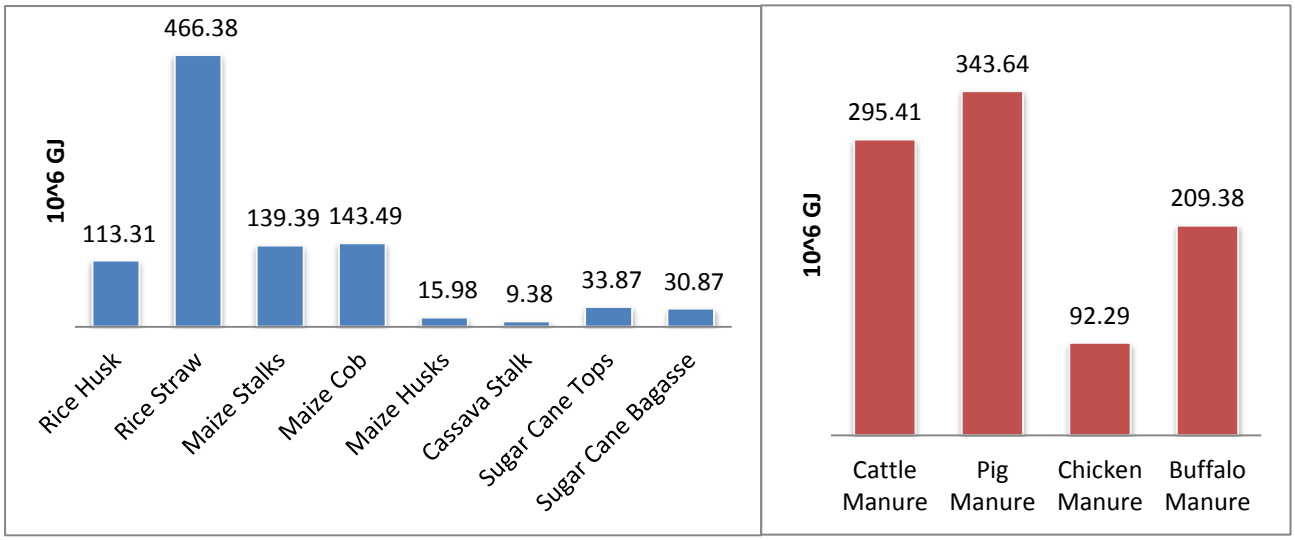


Figure 26: Estimated annual tonnage of agricultural and livestock residue in Viet Nam

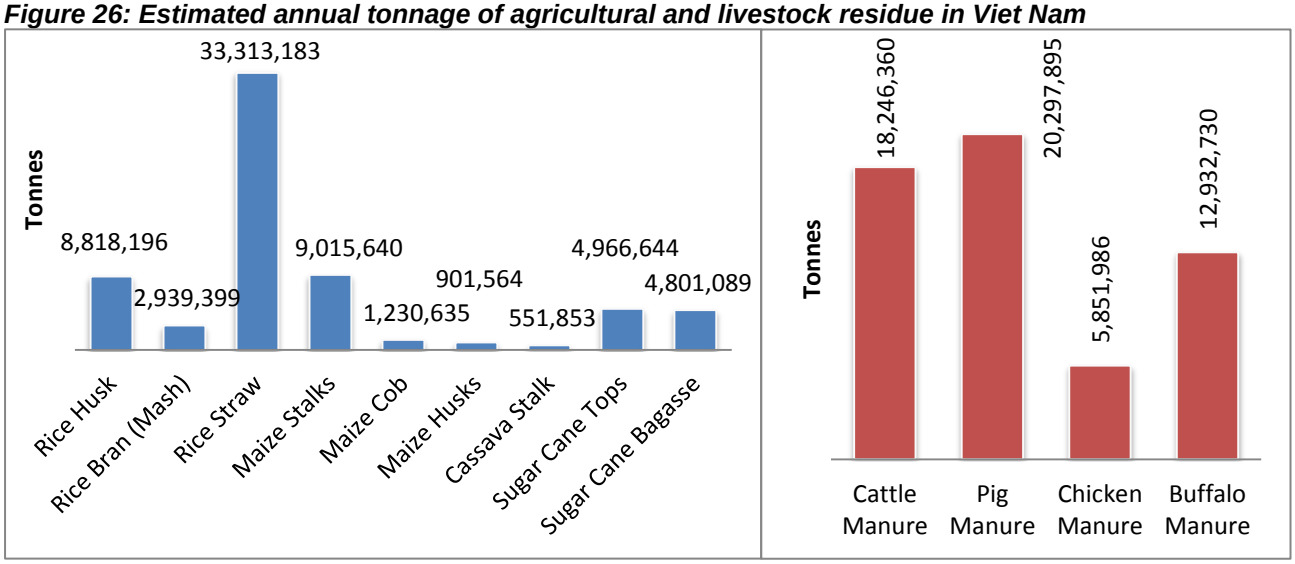


Figure 27: Potential energy of crop residues as a percentage of primary energy use in Viet Nam

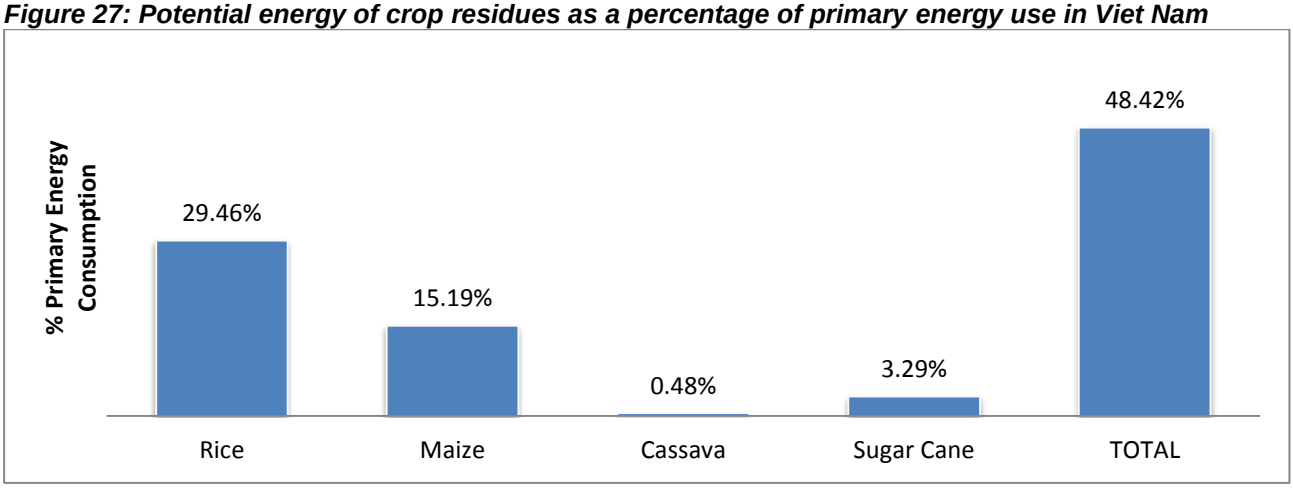
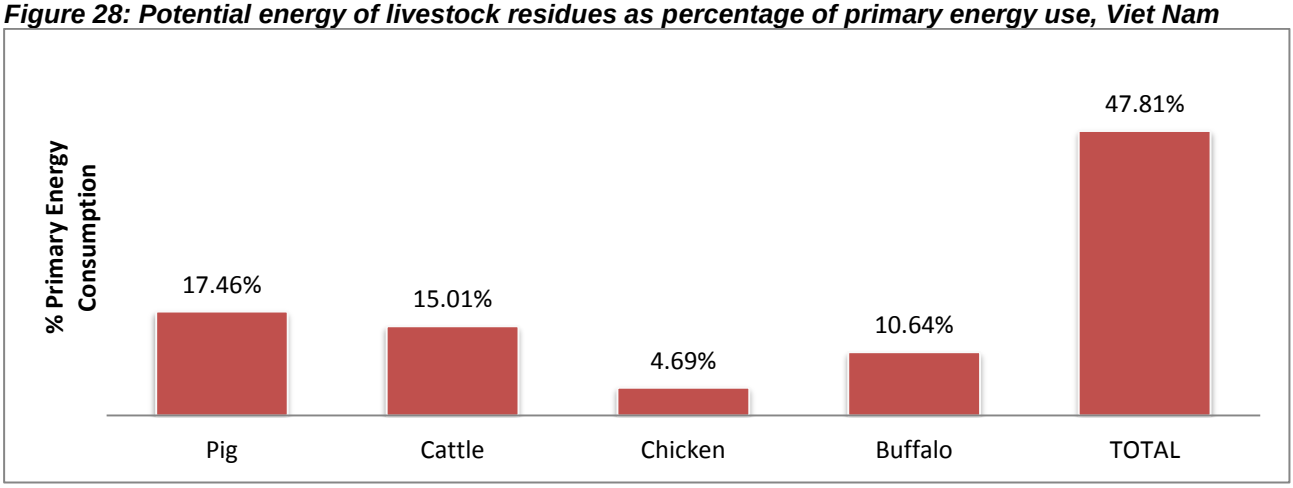


Figure 28: Potential energy of livestock residues as percentage of primary energy use, Viet Nam



APPENDIX 1: DATA ASSUMPTIONS FOR CALCULATIONS

1. CROPS

Table A1.1: Rice residue availability & potential energy

VARIABLE	COUNTRY	VALUE	SOURCE
RPR - Husk	Cambodia	0.240	TA7833 field findings
	Lao PDR	0.200	TA7833 field findings
	Viet Nam	0.225	TA7833 field findings
RPR - Rice Straw	Cambodia	1.222	TA7833 field findings
	Lao PDR	1.000	TA7833 field findings
	Viet Nam	1.000	TA7833 field findings
RPR - Bran/Mash	Cambodia	0.110	TA7833 field findings
	Lao PDR	0.110	TA7833 field findings
	Viet Nam	0.075	TA7833 field findings
LHV - Rice Husk (MJ/kg)	All	12.850	Akgun et al (2011)[4]
LHV - Rice Straw (MJ/kg)	All	14.000	Akgun et al (2011)

Table A1.2: Maize residue availability & potential energy

VARIABLE	COUNTRY	VALUE	SOURCE
RPR - Stalks	All	2.000	FAO (1997)[5]
RPR - Cob	All	0.273	FAO (1997)
RPR - Husks	All	0.200	FAO (1997)
LHV - Stalks (MJ/kg)	All	16.990	Gaur, S. (1995)[6]
LHV - Cob (MJ/kg)	All	17.490	Kitani, O. (1989)[7]
LHV - Husks (MJ/kg)	All	17.730	Evans, R. et al. (1988)[8]

Table A1.3: Cassava residue availability & potential energy

VARIABLE	COUNTRY	VALUE	SOURCE
RPR – Stalks	All	0.062	FAO (1997)
LHV – Stalks (MJ/kg)	All	16.990	Akgun et al (2011)

Table A1.4: Sugar cane residue availability & potential energy

VARIABLE	COUNTRY	VALUE	SOURCE
RPR - Tops	All	0.300	FAO (1997)
RPR - Bagasse	All	0.290	FAO (1997)
LHV - Tops (MJ/kg)	All	6.820	Akgun et al (2011)
LHV - Bagasse (MJ/kg)	All	6.430	Akgun et al (2011)

[4] Akgun et al. (2011). Theoretical Bioenergy Potential in Cambodia and Laos. World Energy Congress 2011. Sweden.

[5] Koopmans, A., Koppejan, J. (1998). Agricultural and Forest Residues – Generation, Utilization and Availability. Proceedings of the Regional Expert Consultation on Modern Applications of Biomass Energy. FAO Regional Wood Energy Development Programme in Asia. Report No. 36, Bangkok.

[6] Gaur, S., Reed, T.B. (1995). An Atlas of Thermal Data for Biomass and Other Fuels. NREL/TP-433-7965, June 1995

[7] Kitani, O., Hall, CW. (1989). Biomass Handbook, Gordon and Breach science publishers, New York.

[8] Evans R, et al. (1988). Development of biomass gasification to produce substitute fuels, Richland, Washington, USA, Pacific Northwest Laboratory (PNL), PNL--6518, 14 p.

2. LIVESTOCK

For all livestock categories, the estimated amount of available bioslurry produced from predicted manure quantities was calculated. This calculation assumed the following:

- Change in volume when passing through the anaerobic digestion process is negligible
- Therefore, 1 cubic meter (m^3) manure = 28.3 liters (l) bioslurry
- Specific weight of manure is equal to 58.5 pounds per cubic feet (lb/ft^3)
- 1kg = 2.20462lb

These assumptions provide for the following equation for total bioslurry availability:

$$Total\ Bioslurry = Total\ Manure\left(\frac{1000kg}{t}\right)\left(\frac{2.20462lb}{kg}\right)\left(58.5\frac{lb}{ft^3}\right)^{-1}\left(\frac{28.3L}{ft^3}\right)\left(\frac{1m^3}{1000L}\right)$$

Table A1.5: Cattle manure quantities & potential energy

VARIABLE	COUNTRY	VALUE	SOURCE
Manure/head (t/yr)	Cambodia	4.00	Field Note
	Lao PDR	4.40	Field Note
	Viet Nam	3.00	Field Note
LHV (MJ/kg)	All	16.190	Sweeten et al (1986)[9]
Manure weight (lb/ft^3)	All	58.500	GDS (2012)[10]

Table A1.6: Pig manure quantities & potential energy

VARIABLE	COUNTRY	VALUE	SOURCE
Manure/head (t/yr)	Cambodia	2.00	Field Note
	Lao PDR	1.10	Field Note
	Viet Nam	0.750	Field Note
LHV (MJ/kg)	All	16.930	ECN (1999) [11]
Manure weight (lb/ft^3)	All	58.500	GDS (2012)

Table A1.7: Chicken manure quantities & potential energy

VARIABLE	COUNTRY	VALUE	SOURCE
Manure/head (t/yr)	Cambodia	0.08	Field Note
	Lao PDR	0.02	Field Note
	Viet Nam	0.03	Field Note
LHV (MJ/kg)	All	15.77	Anton et al. (2000)[12]
Manure weight (lb/ft^3)	All	58.500	GDS (2012)

[9] *Sweeten et al. (1986). Combustion of cattle feedlot manure for energy production. Energy in Agriculture 5 pp. 55-72.*

[10] *GDS. (2012). Implementing the Value Chain-Based GHG Emissions Assessment for Vietnam. September 2012.*

[11] *ECN Laboratories – Phyllis Database. ID#1715. www.ecn.nl/phyllis2. Accessed 8 July 2013.*

[12] *Anton et al. (2000). Poultry litter as a fuel for a fluidised bed incinerator. In: Biomass for energy and industry. Proc. 1st World conference and exhibition, Sevilla, 5-9 June 2000 (Eds. S.Kyritsis et al.)*

Table A1.8: Buffalo manure quantities & potential energy

VARIABLE	COUNTRY	VALUE	SOURCE
Manure/head (t/yr)	Cambodia	6.00	Field Note
	Lao PDR	6.40	Field Note
	Viet Nam	4.50	Field Note
LHV (MJ/kg)	All	16.930	Sweeten et al (1986)
Manure weight (lb/ft^3)	All	58.500	GDS (2012)

3. ENERGY USE

Table A1.9: Primary Energy Consumption in Cambodia, Lao PDR & Viet Nam[13]

COUNTRY	QUADRILLION BTU	10^6 GIGAJOULES
Cambodia	0.660	696.34
Lao PDR	0.045	47.48
Viet Nam	1.865	1,937.68

Other assumptions include:

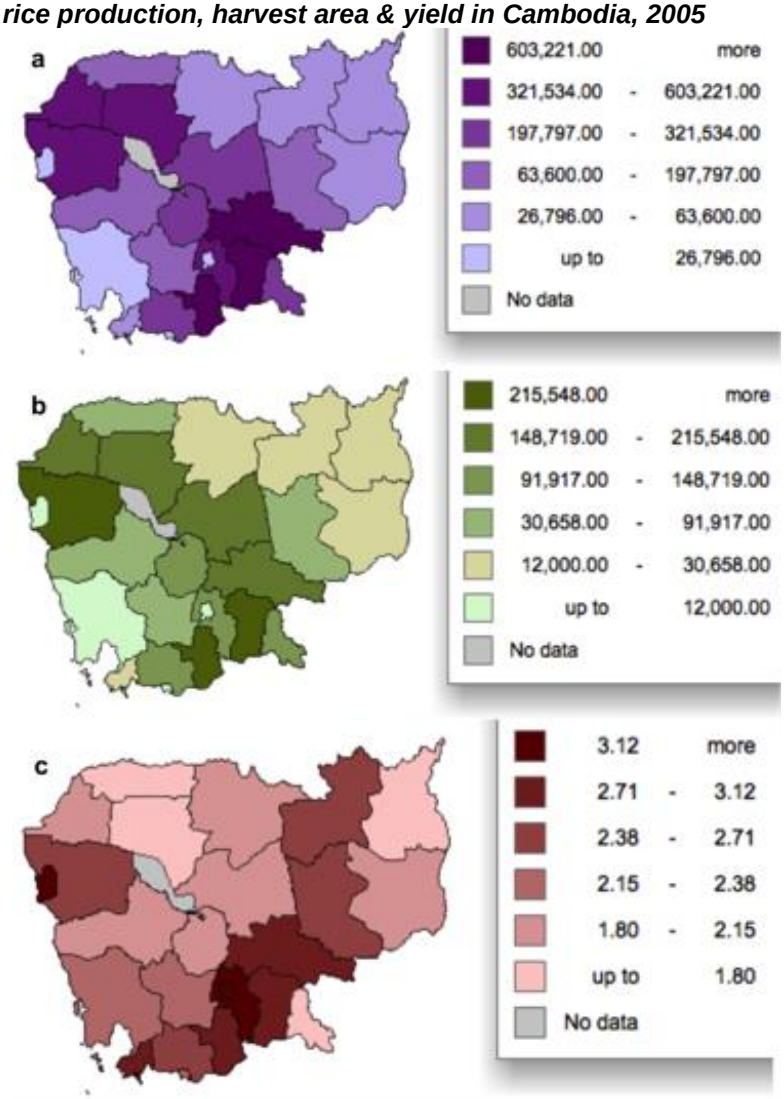
- Primary energy use is considered to equal consumption of petroleum, dry natural gas, coal, net hydroelectric, nuclear, geothermal, solar, wind, wood and waste electricity. Also includes net electricity imports.
- 1 BTU = 1.05506 x 10^{-6} GJ
- 1 kWh = 0.0036 GJ
- Crop potential energies equal to sum of multiple residues
    - Rice = Husk + Stalk
    - Maize = Stalk + Cob + Husk
    - Cassava = Stalk
    - Sugar Cane = Tops + Bagasse

[13] *EIA. Accessed 15 July 2013. For more details on figures, see: http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm*

APPENDIX 2: REGIONAL DATA EXAMPLES

1. CAMBODIA

Figure A2.1: Paddy rice production, harvest area & yield in Cambodia, 2005



Source: Agro-MAPS, 2013[14]

Table A2.1: Livestock populations in provinces of Cambodia, 2005 [15]

PROVINCE	CATTLE	BUFFALO	PIGS	POULTRY
Banteay Meanchey	90,023	11,524	111,251	341,090
Battambang	176,749	6,640	135,763	760,122
Kampong Cham	409,073	72,242	216,910	1,587,787
Kampong Chhnang	185,455	43,331	133,227	483,241
Kampong Speu	338,648	924	138,493	710,942
Kampong Thom	212,833	44,434	84,058	920,890
Kampot	245,688	10,368	182,940	1,032,437
Kandal	167,514	10,510	157,683	1,000,800

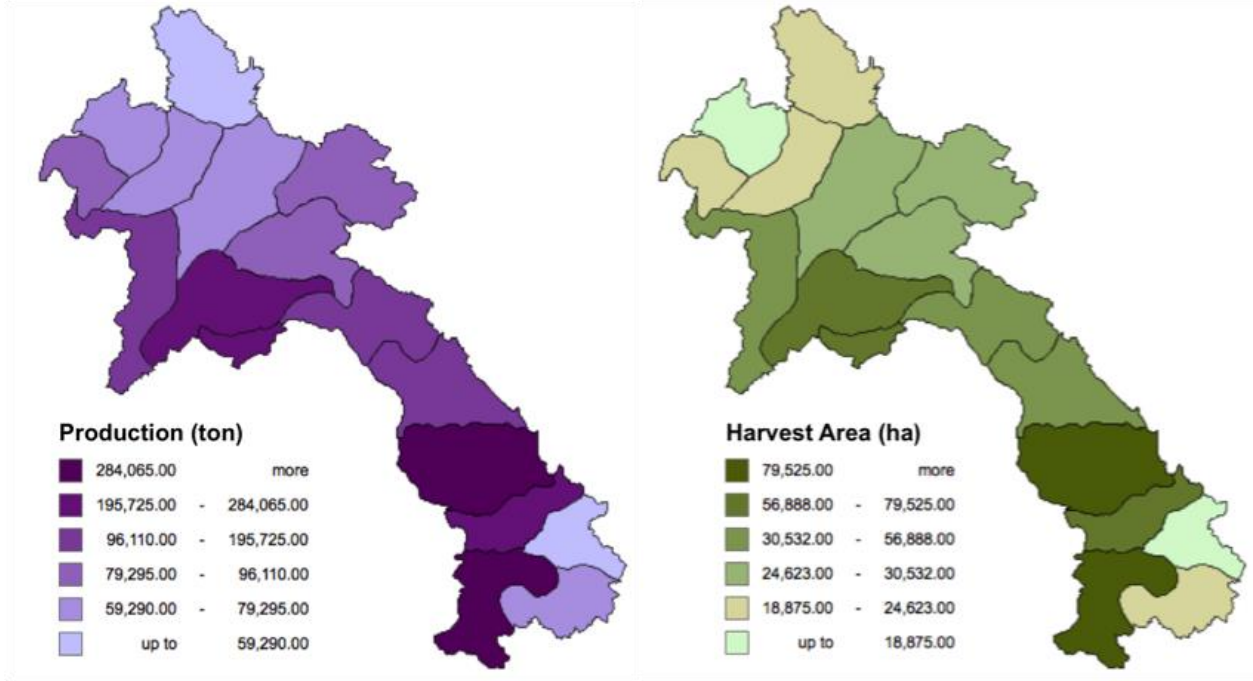
[14] *Agro-Maps. (2013). Global Spatial Database of Agricultural Land-use Statistics. Food and Agriculture Organization of the United Nations (FAO). FAO Land & Water Agro-Maps. Accessed on 29 April 2013.*

[15] *FAO-RAP. (2013). Regional Data Exchange System on Food and Agricultural Statistics in Asia and Pacific Countries. Food and Agriculture Organization of the United Nations (FAO, Region Asia Pacific (RAP. www.faorap-apcas.org. Accessed on 29 April 2013.*

Koh Kong	6,636	8,028	18,803	56,355
Kratie	88,465	42,494	66,517	383,571
Mondulkiri	12,946	7,987	13,018	51,644
Phnom Penh City	22,661	114	15,539	119,935
Preah Vihear	95,296	51,380	158,050	564,965
Prey Veng	245,252	78,849	282,486	1,379,471
Pursat	79,564	74,451	73,786	638,353
Ratanakiri	24,550	17,323	34,903	108,213
Siem Reap	245,342	37,014	137,176	963,181
Preah Sihanouk Town	7,408	5,453	13,162	128,543
Stung Treng	19,753	28,858	23,778	72,621
Svay Rieng	121,541	115,315	322,136	1,451,954
Takeo	308,809	4,382	323,614	2,104,096
Odar Meanchey	67,261	4,899	37,108	166,069
Kep Town	9,626	117	4,846	39,215
Pailin Town	3,053	9	3,365	20,052

2. LAO PDR

Figure A2.2: Paddy rice production and harvest area in Lao, 2008



Source: Agro-MAPS, 2013

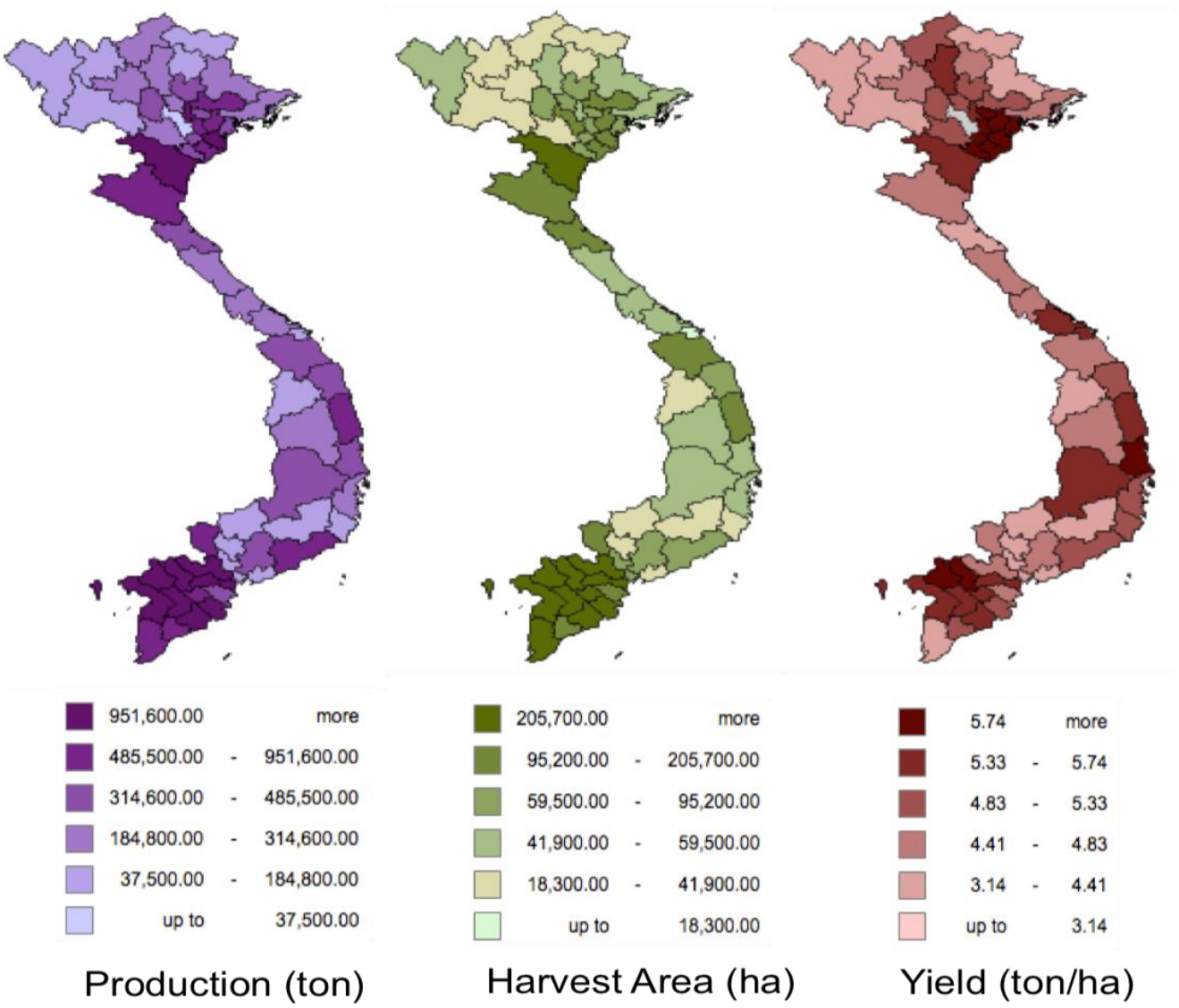
Table A2.2: Rice production residues in Lao PDR, 2004 [16]

PROVINCE	TOTAL RICE PRODUCTION		RICE PRODUCTION RESIDUES			RICE RESIDUES PER HOUSEHOLD (t/HH/hr)
	PRODUCTION(t)	PLOTS	RICE HUSK (t/yr)	RICE BRAN (t/yr)	RICE STRAW (t/yr)	
Vientiane Capital	295,380	72,771	73,845	29,538	98,460	1.70
Phongsaly	40,730	14,523	10,183	4,073	13,577	0.99
Luangnamtha	63,470	21,652	15,868	6,347	21,157	1.73
Oudomxay	76,250	30,066	19,063	7,625	25,417	1.24
Bokeo	59,410	17,338	14,853	5,941	19,803	1.62
Luangprabang	83,970	33,152	20,993	8,397	27,990	0.86
Houaphanh	82,960	26,925	20,740	8,296	27,653	1.32
Xayaboury	139,550	44,816	34,888	13,955	46,517	1.59
Xiengkhouang	70,000	24,996	17,500	7,000	23,333	1.37
Vientiane	204,720	52,316	51,180	20,472	68,240	2.09
Borikhamxay	127,080	34,745	31,770	12,708	42,360	2.35
Khoummouane	154,230	51,830	38,558	15,423	51,410	1.73
Savannakhet	533,305	155,034	133,326	53,331	177,768	2.85
Saravane	228,610	69,923	57,153	22,861	76,203	2.95
Sekong	13,490	4,600	3,373	1,349	4,497	0.71
Champasack	304,510	95,740	76,128	30,451	101,503	2.02
Attapeu	39,560	15,963	9,980	3,956	13,187	1.42
Xaysomboon	11,775	3,3930	2,944	1,178	3,925	1.34

[16] *Asia Pro Eco. (2005).Organic Residues Potential Report [Task D 3.2.3]. Asia Pro Eco Project TH/Asia Pro Eco/05 (101302). Table 1-1 Rice Production in Lao PDR.*

3. VIET NAM

Figure A2.3: Paddy rice production, harvest area & yield in Vietnam, 2005



Source: Agro-MAPS, 2013